



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

TRANSLATOR'S DECLARATION

Commissioner for Patents  
Washington, D.C. 20231

Sir:

I, the below-named translator, certify that I am familiar with both the German and the English language, that I have prepared the attached English translation of a German-language Patent Application entitled, "Insulation for Piezoceramic Multilayer Actuators," and I hereby certify that this translation is an exact and literal translation of the said document.

I further declare that all statements made in this declaration of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that these statements were made with the knowledge that willful, false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful, false statements may jeopardize the validity of legal decisions of any nature based on them.

Respectfully submitted,

Date

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By

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## INSULATION FOR PIEZOCERAMIC MULTILAYER ACTORS

[001] The invention relates to a method for the manufacture of piezoelectric multilayer actors - called "actors" hereinafter - according to the introductory part of Claim 1, and to an actor manufactured by this method.

[002] Piezoceramic multilayer actors (see Fig. 1) in the state of the art consist of stacked thin layers of piezoelectrically active material 2, e.g., lead zirconate titanate (PZT) with conductive internal electrodes 7 arranged between them, which run alternately to the surface of the actor. External electrodes 3 and 4 connect these internal electrodes together. The internal electrodes are thereby connected electrically parallel and in a combination of two sets constituting the two terminal poles of the actor. If an electrical voltage is applied to the terminal poles it is transferred parallel to all of the internal electrodes and cause an electrical field in all layers of the active material which is thereby deformed mechanically. The sum of all these mechanical deformations is available at the end surfaces of the actor as useful expansion 6 and/or force.

[003] Piezoceramic multilayer actors are, in the state of the art, made in the form of monoliths, that is, the active material in the form of so-called green films are provided by screen printing methods with internal electrodes prior to sintering, pressed into actor stacks, pyrolyzed and then sintered, resulting in the monolithic actor.

[004] A metal ground coating 3 is applied to the actor stack 1 in the area of the brought-out internal electrodes 7, e.g., by screen printing with metal paste. This metal ground coating is strengthened by applying a metal material 4, e.g., by soldering on an embossed plate or a wire mesh. The electrical connecting wire 5 is soldered onto this strengthened coating.

[005] The structure and the manufacture of such actors and external electrodes is thoroughly described, e.g., in DE 33 30 538 A1, DE 40 36 287 C2, US 5 281 885, US 4 845 399, US 5 406 164 and JP 07-226541 A.

[006] The spacing between the internal electrodes 2a of different polarity leading out interdigitally is so small that a flashover would take place at the surface at the working voltage.

Therefore the surface is usually covered with an insulating varnish. The fact that thin varnishes offer only an insufficient protection against contact and are mechanically delicate is a disadvantage. Thick varnishes, on the other hand, tend to come loose in operation or when exposed to temperature change. The expression, interdigital areas, is to be understood to refer to the outwardly leading internal electrodes 2a in Fig. 1 between the contacted sides 3 and 4.

[007] Another possibility is to keep the electrodes from reaching all the way to the surface ("buried electrodes"), or to have only the electrodes of one polarity emerge at the surface ("half-buried electrodes"). The disadvantage is that the active surface is diminished and thus the development of the actor's power is reduced. At the same time these inactive zones result in a cramping of the actor and are liable to crazing.

[008] Another possibility for protecting the surface is to apply a ceramic film to the green surface of the actor, sintered them with the actor in order thus to achieve insulation (DE 10 021 919 A1). A disadvantage in this method is that the outside dimensions of the actor cannot be reproduced very accurately due to shrinkage during sintering. Moreover, this insulating layer is made relatively thick by the process (typically  $>50\text{ }\mu\text{m}$ ) and thus has disadvantages similar to the two methods described above.

[009] The invention is addressed to the problem of achieving insulation with a ceramic which can be applied after sintering and shaping by grinding and thus can satisfy even severe geometric requirements.

[010] According to the invention this problem is solved by the features of claim 1.

[011] Advantageously the coating takes place after the sintering and shaping, and the coating is fired on at temperatures between  $400$  and  $1200^{\circ}\text{C}$  or between  $600$  and  $1000^{\circ}\text{C}$ , or preferably between  $650$  and  $850^{\circ}\text{C}$ .

[012] Preferably the firing of the insulating layer takes place together with the firing on of the external electrode and forms a continuous coating.

[013] In an alternative embodiment, the application of the insulating coating is made after the polarization of the actor and, by drying at  $20$  to  $250^{\circ}\text{C}$ , preferably at  $80$  to  $120^{\circ}\text{C}$ , all electrodes

of one polarity are covered, but not the electrodes of the other polarity, and thus no continuous coating is formed.

[014] Preferably the low-sintering material is PZT (lead-zirconate-titanate) and/or it is identical with the actor material.

[015] Advantageously, the thick coating paste consists of a glass and an organic binder system.

[016] Preferably the thick coating paste is applied to the green actor body and sintered together with the latter.

[017] In an advantageous embodiment the thick coating is applied by silk-screen printing, rubber-stamping or rolling or by plasma spraying.

[018] An actor which is made by the method of the invention serves advantageously for the control of an injection valve in motor vehicles.

[019] Additional features of the invention will appear from the figures and the embodiments which are described below.

[020] The surfaces to be insulated are coated by thick layer methods with a paste consisting of low-sintering PZT (known, for example, from DE 19 840 488 A1) and an organic binder system. This insulating coating is fired on at temperatures between 500 and 1200°C, preferably between 600 and 900°C.

[021] In another embodiment the actor is polarized before the screen-printed coating is applied, so that, when the paste is dried at 80-120°C pyrotension is the result. Due to electrophoretic processes this pyrotension brings the result that only every second electrode becomes coated with PZT particles. As a result, an outstanding insulation of the electrodes of different polarity is assured after sintering, without the surface being covered by a coherent layer to interfere with expansion or the development of power in the actor.

[022] Embodiments:

[023] The actor is constructed as usual by bringing the electrodes out interdigitally on all sides, but not on the surfaces that are to be contacted. The actor's green body is sintered and can be subjected to high-precision shaping by grinding. Then the base metallization of the external electrode (making contact with electrodes of one polarity) can be applied by silk screen printing.

[024] Method 1: The insulating coat 8 is applied by thick layer methods together with the external electrode layers (ground metallization) and fired on together ( $600 < TS < 900^{\circ}\text{C}$ ). The insulating coat now covers all of the interdigital areas 8 of the actor with a coating between 2 and 20  $\mu\text{m}$ , preferably 4-15  $\mu\text{m}$ , thick. The latter is strongly adherent and scratch-resistant and interferes but negligibly with the stroke or power development of the actor (Fig. 2). Then the external electrode is soldered to a screen 9 and further contacted 10. Figure 2 shows an actor with external electrodes, insulated by screen printing (full-surface).

[025] Method 2: The external electrode (ground metallization) is fired. The actor is then polarized and on the surfaces, which have an interdigital structure, a paste is applied, consisting of low-sintering PZT and an organic binder system. When the paste is dried at  $20\text{-}250^{\circ}\text{C}$ , due to the pyroelectric effect of the ferroelectric ceramic, an electric field is produced in the still not dried paste. Consequently, electrophoretic processes occur in the paste, so that only every second internal electrode is covered (electrodes of one polarity (Fig. 3, No. 12). The electrodes 11 of the other polarity are not covered. A subsequent firing process at temperatures around  $750^{\circ}\text{C}$  results in an adherent and scratch-resistant insulation (Fig. 3). Figure 3 shows the insulating surface of an actor with internal electrodes 11 and insulation 12 of every second internal electrode by silk-screen printing (interrupted).